A quest for the Holy Grail: Tactile precision, natural movement and haptic feedback in 3D virtual spaces

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Three-dimensional immersive spaces such as those provided by virtual worlds, give unparalleled opportunities for learners to practically engage with simulated authentic settings that may be too expensive or too dangerous to experience in the real world. The potential afforded by these environments is severely constrained by the use of a keyboard and mouse moving in two dimensions. While most technologies have evolved rapidly in the early 21st century, the mouse and keyboard as standard navigation and interaction tools have not. However, talented teams from a range of disciplines are on serious quests to address this limitation. Their Holy Grail is to develop ways to interact with 3D immersive spaces using more natural human movements with haptic feedback. Applications would include the training of surgeons and musical conductors, training elite sports people and even physical rehabilitation. This paper reports on the cutting-edge technology projects that look most likely to provide a solution for this complex problem, including the Wiimote and the Microsoft's Project Natal.

Keywords: 3D, virtual worlds, haptic, Wii, immersion

Introduction

Although there is great fanfare about the potential of three-dimensional immersive spaces for application to higher education, there are still significant shortcomings in the available technologies that need to be addressed to reliably harness that potential. An obvious example is the constraint of natural movement in these spaces due to the limited flexibility afforded by the conventional mouse and keyboard. A further constraint is the lack of haptic (tactile) feedback when interacting with virtual objects. For many reasons, achieving more natural motion, tactile precision and haptic interaction remains a Holy Grail for human-computer interface designers across disciplines as diverse as gaming, IT, engineering, health sciences and education.

Propelled by the lucrative consumer market, gaming developers are at the forefront in the quest to radically change the way users interact with 3D immersive spaces. Speed, responsiveness and dimensional motion are generally not facilitated by most user interfaces, diminishing the participant's experience (Champy, 2007). Further, gaming developers are focused on how to best exploit intuitive skills through tangible user interfaces (TUIs) and intuitive tangible controls. Xin and colleagues (Xin, Watts, & Sharlin, 2007) have reinforced the value of this research, discovering that sensory immersion is enhanced in games using such controls. The provision of haptic feedback further enhances the immersive experience, leading to heightened believability through interaction with 3D objects (Butler & Neave, 2008).

For university educators, being able to incorporate these attributes into spaces like Massively Multiplayer Online Role-playing Games (MMORPGs) such as World of Warcraft and Ultima Online or into Multi-user Virtual Environments (MUVEs) such as Second Life and Active Worlds would also amount to a Holy Grail in terms of giving their students authentic learning experiences that resemble real life tasks and scenarios. What better way to train an architect than to let them design and construct a building; walk around in it when completed and then go back and correct any deficiencies or experiment with alternatives? A prospective surgeon could learn to perform complex surgeries on a patient that cannot die and a student of history could gain a sophisticated understanding of historical events. The educational affordances are endless.

The aim of this paper is to report on the current 'state-of-play' in the quest for natural movement, tactile precision and haptic feedback in 3D virtual spaces. The authors have attempted to synthesise significant developments in interface design, controllers, devices and software that together represent an exciting shift in the possibilities for educators and learners in 3D immersive environments. In particular, using this review, we seek to answer the following questions:

1. What are the educational and other benefits of tactile precision, natural movement and haptic feedback in 3D virtual spaces?
2. What are the current and emerging technologies that exhibit the potential for tactile precision, natural movement and haptic feedback in 3D virtual spaces?

Method

Search and selection procedures

Research relevant to these questions was identified through a systematic search and selection process. The authors generated lists of relevant keywords in combination with Boolean operators to search electronic databases including A+ education and Compendex which yielded peer-reviewed articles and conference papers from a number of disciplines, as well as conference proceedings related to educational technology, ICTs and simulations. Articles and papers were initially screened by title and abstract. Websites, blogs, videos and other electronic sources known to feature content about gaming interfaces and technological innovation were also examined, with the authors subscribing to the RSS feeds associated with these resources through the duration of this investigation to ensure currency and relevance. Given the rapidly changing and competitive development environments, particularly in the gaming and IT industries, as well as the time lag associated with the publication of peer-reviewed articles, reports on current and emerging technologies are often out-of-date by the time they appear in highly esteemed journals. Thus, when analyzing the development trends of technologies capable of motion and haptic attributes for 3D virtual spaces, a deliberate decision was made to draw upon conference papers and alternative sources that may not have been subjected to rigorous peer review. While this is a notable limitation of this paper, it is a defensible one. Innovators who are employed in these industries use similar sources to communicate their ideas and evaluate the status and trends in the development of cutting edge technology. However, a further weakness of this approach, as highlighted by Miller and Roberston (2009), is that the quality and objectivity of information is more difficult to guarantee. However, given that we are reporting on such recent and emerging technologies, this was unavoidable. We have endeavored to take due care to critically analyse the information sources retrieved to minimize this shortcoming.

Analysis

In this kind of report from the field, the unit of analysis was the individual article, website, report, blog, video or other relevant source. After surveying each source for information related to the research questions, relevant content was noted by each author in relation to the current and emerging technologies that facilitate authentic movement and haptic feedback in three-dimensional virtual spaces. A constant comparative method or grounded approach (Lincoln & Guba, 1985) was applied to generate categories across all information gathered. This was done independently and then discussed by the authors until agreement was reached. This approach enabled a thorough exploration of the contemporary developments and applications of the types of technologies under investigation.

Findings and discussion

This section presents the findings of our review and discusses the benefits and potential for application to tertiary education environments. Although we have categorised sub-sections, in line with our methodology described in the previous section, there is a natural overlap between the questions we are addressing. For this reason, examples that illustrate the educational potential of tactile precision, natural movement and haptic feedback in 3D virtual spaces are peppered through both areas of enquiry.

What are the educational and other benefits of tactile precision, natural movement and haptic feedback in 3D virtual spaces?

For some disciplines, the current educational affordances of virtual spaces such as Second Life are obvious (Salmon, 2009). These environments are so appealing to students and educators because the senses are stimulated, evoking emotional responses, and introducing new ideas in fresh and exciting ways. Through increasing the potential for genuinely immersive experiences, the unique attributes of 3D environments would be fully leveraged by overcoming a range of issues relating to tactile precision, natural movement and haptic feedback. The motivations for overcoming these difficulties will be discussed in the following sub-sections relating to managing risk and costs, overcoming physical challenges and increasing flexibility, immersion and educational opportunities.

Managing risk and costs
Virtual environments are extremely useful when training students to perform tasks that are too expensive or dangerous to perform in real life (Adams, Klowden, & Hannaford, 2001). Well-designed simulations implemented in these environments can provide risk-averse and cost-effective simulations of authentic contexts that can facilitate optimal learning, especially when enhanced with the capability for tactile precision and haptic feedback. An obvious example would include learning to fly. Flight simulator training, in conjunction with training with an aircraft, has been found to be more effective than training with an aircraft alone (Hays, Jacobs, Prince, & Salas, 1992). Another example is learning to perform surgery. In surgical education, it has been reported that the student learns from immediately seeing the consequences of his or her own actions (Gorman, Meier, & Krummel, 1999). Such a scenario can be recreated in a virtual environment. In addition, these scenarios can result in a significant reduction in cost. The real cost of training chief residents in the operating room was estimated to have run to approximately $USD 53 million dollars in the US over ten years ago (Bridges & Diamond, 1999). Thus the fiscal incentive for developing virtual training is substantial. Cost-saving could also be a significant factor if complex surgeries are planned by practising them first in a virtual environment. Intricate or complicated procedures could be attempted virtually in order to discern the safest and most efficient approach thereby decreasing risk to the patient, and reducing costs (Gorman et al., 1999). However, to enable successful medical and surgical simulations in a virtual environments, there would need to be haptic feedback to create a degree of realism not present in standard interfaces (Hayward, Astley, Cruz-Hernandez, Grant, & Robles-De-La-Torre, 2004). Haptic clues provide information about weight, surface structure, size, flexibility and shape (Luursema, Verwey, Kommers, & Annema, 2008).

Overcoming physical challenges
In their current form, navigation around virtual spaces using a keyboard and mouse moving in two dimensions means that users encounter a range of physical challenges. These include:

- the functional isolation of participants (Xin et al., 2007),
- the restriction of intuition and freedom of movement (Fassbender & Richards, 2008),
- challenges for children, elderly people or those with disabilities who may lack the ability to precisely coordinate keyboard strokes and mouse actions (Cardoso, Melo, Gomes, Kehoe, & Morgado, 2007; Kim, Roh, & Kim, 2008),
- the limitation of the way educators can capitalise on the common knowledge that people possess from their everyday physical interactions in the real world (Xin et al., 2007).

Enabling more natural movement would overcome these kinds of issues and extend both the inclusiveness and capability of these environments for education and training.

Increasing flexibility, immersion and educational opportunities
The ability of virtual 3D spaces to be more interactive in terms of tactile precision, natural movement and haptic feedback, confers a substantial educational benefit and makes learning experiences flexible in terms of time, place and opportunity. Dede (2009) defines immersion as: 'the subjective impression that one is participating in a comprehensive, realistic experience' (p. 66). Various technologies facilitate sensory immersion that locates learners' experiences in three-dimensional space. Visual stimulation, stereoscopic sound and haptic technologies enhance this sensory immersion and the subsequent suspension of disbelief (Dede, 2009). There is evidence to suggest that game technologies leverage immersion to improve learner motivation and engagement (Fassbender & Richards, 2008). Potentially, learners will be able to participate equitably irrespective time and location, academic achievement and to a more limited extent, disability. Further, situated learning via the provision of authentic activities, contexts and assessment is a powerful pedagogical tool that can be readily leveraged in a virtual environment utilizing authentic 3D movement. For example, allowing students of anatomy to change the

perspective shown by rotating a virtual object, helps them to develop visuo-spatial representations (Luursema, Verwey, Kommers, & Annema, 2006). This ability to conceptualise 3D shapes is enhanced by the use of haptic technology, making it easier to learn about objects that ordinarily could not be touched or walked around because of substantial risks in real-life settings (Dettori et al., 2003). An example that comes to mind is a project conducted by one of the authors involving the teaching of veterinary students about the rectal palpation of cows for pregnancy testing and to develop practical and theoretical knowledge of bovine reproduction processes. This project, which won an ascilite President's Award in 2007, (see http://www.ascilite.org.au/index.php?p=ascilite_awards_2007#Online), would have been considerably enhanced if there were cost-effective technologies available to provide tactile precision, natural movement and haptic feedback. Furthermore, situated learning enhances transfer, such that skills and knowledge learned in one environment can be readily transferred to another; perhaps a skill performed in a real life setting (Dede, 2009).

The human brain is wired to believe that all it sees is real and this includes images on a screen from a virtual world. From an evolutionary point of view, this occurs because for the vast majority of human evolution there have not been virtual environments and virtual objects. When a participant sees a tiger in a virtual environment, it takes energy to remind him or herself that it is not real. As virtual environments become more similar to reality, the brain has to work harder to differentiate the real from the virtual and the motivation for doing so, particularly if the experience is engaging or pleasant, is significantly decreased (Castronova, 2001). This is an important realization: if simulations in virtual spaces are sufficiently engaging and realistic, and that realism can be augmented by the use of authentic input devices, then the motivation for distinguishing virtual from real is sufficiently low that for all intents and purposes, learners *are* actually engaged in practising authentic physical skills and receiving relevant haptic feedback with corresponding application in the 'real' world.

What is the current and emerging technological potential for tactile precision, natural movement and haptic feedback in 3D virtual spaces?

> Of course, when playing a game, the nearest thing to the player is the controller. The controller should therefore be regarded as an extension of the player rather than as part of the console. I always bear in mind the importance of the fact that the player will have far more contact with the controller and UI [user interface] than the console itself. (Akio Ikeda, responsible for accelerometer hardware in the Nintendo Wii ™, in an interview with Satoru Iwata, Wiilaunch website, Summer 2006.)

Although the velocity of growth in IT-related development continues to be exponential, there has only been limited success in exploiting human spatiality, senses, innate human physical movements and tactile precision in interfacing with computer-generated environments. In fact, as stated by Xu (2005), 'It is commonly believed that physical action is important in learning, and tangible objects are thought to provide different kinds of opportunities for reasoning about the world. Arguably, many classic computer interactions offer very limited stimuli, little freedom to behave and low ecological validity (that is, little relevance to normal, everyday human behaviour in the real world)' (p.1). In searching for technologies that offer potential to be adapted to learning tasks in virtual 3D spaces, we were particularly interested in those that could support the application of theory-to-practice and would be enhanced by more tactile precision, natural movement and haptic feedback. Several categories of technologies emerged that encompassed tangible user interfaces, haptic interfaces and devices, controllers for tactile precision and natural movement, floor devices for natural movement, other gaming remotes for natural and tactile movement, and other software that facilitated three-dimensional movement.

Tangible user interfaces

According to Sharlin and Watson (2004), tangible user interfaces (TUIs) are 'objects manipulated by humans' and their effectiveness is dependent on 'how well they exploit spatiality, the intuitive spatial skills humans have with the objects they use' (p. 338). Sensory immersion is enhanced in games with the use of intuitive tangible controls (Xin et al., 2007). An example would be the game 'Guitar Hero' (Figure 1), a rhythm-based game available for a range of gaming consoles. The game is played using a realistic-looking guitar and utilising realistic guitar-playing hand gestures (Activision., 2005-2009). This enables a direct correlation between interaction in the physical and gaming worlds, thereby enabling players to temporarily suspend disbelief and lose themselves in the game (Xin et al., 2007). Other examples would include the use of the light saber in the Lucasarts game *Star Wars: The Force Unleashed* (Figure 2) where participants battle foes with their weapon (LucasArts, 2009).

Figure 1: Guitar for use with the *Guitar Hero* game

Figure 2: Nintendo Wii lightsaber for use with the *Star Wars: The Force Unleashed*

Haptic interfaces and devices

In learning, the use of haptic devices provides an opportunity to mentally store the tactual image of an object along with its visual image (Katz & Krueger, 1989). When applied to controllers, haptics involves the development of software algorithms that synthesize computer generated forces to be experienced by the user for perception and manipulation of virtual objects through touch (Basdogan & Srinvasan, 2002). Information about the resistance of an object is conveyed to the learner by giving active resistance to certain motions of the user. This mechanism is referred to as 'force feedback' (Bergamasco, Frisoli, & Barbagli, 2002). The ability to have programmable mechanical properties facilitates a bidirectional exchange of energy, and therefore information, between the user and the virtual environment (Hayward et al., 2004). This technology has been extensively used in medicine where it is used for surgical simulation, telemedicine, interfaces for blind people and rehabilitation of patients with neurological disorders (Basdogan & Srinvasan, 2002). Haptics also incorporates the idea of kinesthesia (or proprioception) as the ability to perceive the position of one's body, movement and weight. The term 'haptic channel' collectively designates the sensory and motor components of haptics as the hand, by way of example, perceives the world while acting upon it. Tactile and kinesthetic channels work in conjunction to provide the means to perceive and act on the environment (Hayward et al., 2004).

Haptic Interfaces (HI) are robotic systems which allow users to interact with virtual objects using the sense of touch via the use of force feedback (Bergamasco et al., 2002). The Phantom Omni by Sensable Technologies is an example of a commercialized Haptic Interface (Butler & Neave, 2008). The 3D environment or virtual object is viewed on a screen as the user interacts with it. The main limitation of the Phantom Omni, apart from the high cost, is the restrictive range of movement and the provision of feedback for only one point of contact (Butler & Neave, 2008). There are several variants of the Phantom Omni, but generally a stylus is grasped or the user's finger slides into a thimble so that he or she can have the experience of running a finger over the surface of an object (Hayward et al., 2004). The type of haptic feedback this device utilizes is known as 'point interaction' and allows for six degrees of freedom. A variation of this device which has been used for virtual sculpting is the 'Sensable Phantom Haptic Pen'(Creighton & Ho-Stuart, 2004). The pen also has six degrees of freedom, which is sufficient to give the location and orientation of an object in space (Creighton & Ho-Stuart, 2004). Even so, users report that they would prefer to be able to move around a virtual object, rather than being confined to a single spot (Butler & Neave, 2008). In addition, it is a single user device and its high cost makes it inaccessible for most classroom contexts. Less expensive options are available, such as the Logitech Force 3D Pro but these devices do not have the fidelity or low-level control access needed for many educational simulations (Grow, Verner, & Okamura, 2007). Another alternative would be the force feedback joystick. Though this has fewer degrees of freedom than the Phantom Haptic Pen, it is widely available and is already familiar to many computer users (Butler & Neave, 2008).

By way of contrast, the Museum of Pure Form (Figure 3) is a funded project to enable users to virtually touch fragile and valuable sculptures through a specially designed Haptic Interface and virtual projection system. The HI takes the form of an exoskeleton that fits over the upper arm (Figure 4), providing force feedback with a separate haptic interface for the fingers (PERCO, 2002). The visitor to the museum is able to see the art pieces but is actually interacting with a digital representation of that piece. The haptic feedback is such that to the user it will feel like he or she is moving a hand along the surface of the sculpture (Bergamasco et al., 2002).

The Virtual Reality Glove is another interface controller that utilizes haptic technology. In order to detect hand movements, a strain-gauge sensor or flex sensor measures the physical position of the fingers and micro-actuators provide force feedback. A positioning device measures the 3D coordinates of the glove in space . Unfortunately, the prohibitively high cost of the device, due to its complicated construction and

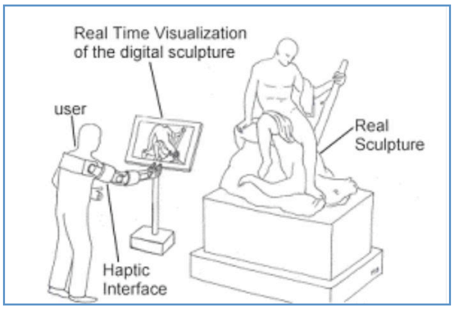

Figure 3: A representation of the Museum of Pure Form system


Figure 4: A user wearing the specially designed Haptic Interface in the form of an exoskeleton in the Museum of Pure Form

expensive components, mean that it has had little application in educational contexts. In addition, the response time tends to be slow, undermining its potential as a controller for authentic 3D movement in a virtual environment. Some, like Goldmeier (2009) categorise these gloves, along with six other virtual reality technology innovations, as failed attempts in recent times.

A controller that holds more promise in this context currently is the Nintendo Wiimote that comes with the Nintendo Wii console. Haptic feedback is simulated via the onboard vibration-producing motor (Brindza & Szweda, 2008). The Wiimote is the device with the most potential for educational use due to its low cost, adaptability and its popularity as a gaming controller. For example, it is expected that the Wiimote will soon be used for interacting with the MUVE, Second Life to provide many exciting possibilities (Boulos, Hetherington, & Wheeler, 2007; Sreedharan, Zurita, & Plimmer, 2007).

Haptic feedback may not be the only advantage conferred by haptic devices; it may become possible to record haptic interactions if some sort of recording device is installed either in the computer generating the virtual environment or the haptic controller. The concept of playing back haptic stimuli to the user may have some useful applications. For example, a user with access to a desktop haptic device may touch and feel the prerecorded textures of a car seat that is advertised by a car company over the Internet. Possibly, preprogrammed haptic devices could be used to rehabilitate patients with neurological damage by displaying pre-recorded haptic trajectories in order to improve their motor-control skills. Alternatively, elite athletes could train virtually and then examine their virtual performances. For example, a runner could examine if the foot hit the ground in a balanced manner or examine motional postures (Basdogan & Srinvasan, 2002).

Controllers for tactile precision and natural movement

The Nintendo Wii also incorporates a number of innovative features that enable more tactile precision. Its most unique feature is the Wiimote (Wii remote) which can detect motion and rotation in three dimensions via three accelerometers and an infrared sensor (Brindza & Szweda, 2008). This is intended to make motion sensitivity more intuitive and natural. The Wiimote is designed to be easy to grasp and point, and makes the device seem more familiar to the non-gaming public. This broadens its use to non-traditional audiences such as the elderly and disabled people. Users control the movements of their avatars (or Miis) in the games by moving their arms while holding the Wiimote (Pearson & Baily, 2007). For example, Wii Sports contains a tennis game and participants play by using the Wiimote as they would a tennis racquet, swinging it as the tennis ball approaches their avatar.

The Wiimote is wireless and communicates with the Nintendo Wii console via Bluetooth. The Wiimote has been reverse engineered, through the contributions of several individuals to the WiiLi and WiiBrew projects (programming libraries), making it possible to both send data to the Wiimote and interpret most of the data received from it. Transmission is through a standard Bluetooth signal, enabling communication between the Wiimote and any computer with a compatible Bluetooth adapter (Brindza & Szweda, 2008). The Wiimote's unique features will facilitate such tasks as motion capture and gesture recognition, ensuring that the device will be used beyond the gaming industry (Brindza & Szweda, 2008). It has already been used successfully for teaching CPR techniques at the University of Alabama in Birmingham to track hand precision and give students feedback on their depth and rate of compression (Coldewey, 2009). The recent release of the Wii MotionPlus has boosted precision and motion-sensing capabilities compared to the original Wiimote, as it can more accurately track the user's arm position and orientation in real time on the screen (Hearn, 2009).

Even with the Wiimote's obvious advantages there are still significant hurdles that need to be overcome before the Wiimote can be used in a wide range of virtual educational contexts. There are very few options for customizing the Nintendo Wii console without buying the expensive official Game Development kit. The kit is intended for use by professional development companies only. In addition, there are very few software tools available to assist development (Morgan, Butler, & Power, 2007). And although the Wiimote has been successfully reverse engineered, there are some aspects that are poorly understood. For example, the speaker embedded in the Wiimote is not yet functional outside of Nintendo-authorized games and will not emit any meaningful audio in any Wiimote library (Brindza & Szweda, 2008). Finally, they are only sensitive to motion in the hand in which they are being held. The addition of a 'nunchuck' which also contains an accelerometer and is attached to the main Wiimote by a cord about one metre long, overcomes this to a certain extent. The nunchuk attachment does lack the inbuilt motor of the Wiimote, so is not able to simulate haptic feedback. Technologies utilizing depth-sensing cameras offer some advantage over the Wiimote (Naone, 2008).

Floor devices for natural movement

Dance pads (Figure 5) originate from *Dance Dance Revolution*, a physically engaging arcade game from Konami (Beckhaus, Blom, & Haringer, 2005; Fassbender & Richards, 2008). The most recent pads consist of a pad with arrows pointing in four directions, two additional arrows pointing at 45 degrees and six buttons. Although most pads were developed for use with game consoles, inexpensive adapters can plug into a PC via a USB interface (Beckhaus et al., 2005). The interface allows for intuitive multi-directional movement in virtual spaces. A team at Macquarie University in Sydney used a dance pad to facilitate movement in a virtual heritage environment, namely the Macquarie Lighthouse course in the Oblivion game engine (Fassbender & Richards, 2008).Though moving in a virtual environment using the dance pad was intuitively easy, there were significant negative aspects. Users tended to be disoriented by the virtual-immersive display system such that they would lose their balance and sway to the side, only stopping themselves from falling completely by putting their feet out to the side of the dance pad. These disquieting feelings were most likely due to a mismatch between proprioceptive and visual inputs (Fassbender & Richards, 2008). Also, the dance pad was insufficiently responsive such that over steering was a common problem making the interface unsuitable for prolonged use in a virtual environment (Fassbender & Richards, 2008).

Figure 5: A recent dance pad

Figure 6: Wii balance board

Another floor device recruited from gaming is the Wii Balance Board (Figure 6). The Wii Balance Board is available for use with the Nintendo Wii console and Wiimotes. Within the gaming context, it is used to play a number of games many of which simulate snowboarding (such as *Shaun White Snowboarding: Roadtrip* and *Snowboard Riot*) and skateboarding (such as *Skate City Heroes* and *Skate It*) (see Hudson Soft, 2009; Ubisoft, 2009). It is also used for balance, aerobic and yoga activities in Nintendo's Wii Fit game. The Wii balance board itself is a sturdy, rectangular panel that rests on four feet each of which contains a pressure sensor. The pressure values are conveyed to the Wii console via Bluetooth (de Haan, Griffith, & Post, 2008).

There are numerous possibilities for movement in three-dimensional space. The most obvious use would be to control first person travel using natural proprioception and kinaesthetic senses. The user would step onto the centre of the balance board and then move to the rim to indicate movement in any direction (de Haan et al., 2008). Engineer David Philip Oster created some software for Bluetooth-enabled Apple computers that enables users to 'surf' Google Earth (Oster, 2009a, 2009b). This software is easy to download, install and use and within minutes it is possible to be exploring the three-dimensional features of the Grand Canyon or the Himalayas. Matthieu Deru and Simon Bergweiler also hacked the Wii Balance Board so that it could be used to surf Google Earth. In addition, they used it as a means of moving avatars in the MUVE of Second Life (Deru & Bergweiler, 2009). It would also be possible to use the balance board while sitting down and in that way could simulate pedal control (de Haan et al., 2008). The board can also be used as rotational input device whereby the user can rotate a particular object.

Further, it would be useful in those contexts when the user's hands are already occupied with another task (de Haan et al., 2008).

Other gaming remotes for natural and tactile movement
A Gyration 'in air' mouse has been used to conduct a virtual orchestra. It was chosen because it was easy to set up, accurate and reliable in a variety of environments (Dillon, Wong, & Ang, 2006). The Gyration in-air mouse is completely wireless and operates up to 30 metres from the computer or console (Gyration, 2009). The game itself shows a view from the conductor's perspective of a standard string orchestra. The user interacts with the orchestra, via a baton which is actually an air gyro mouse, performing hand gestures in order to change the tempo, dynamics and articulation of the music in real time (Dillon et al., 2006). The player's conducting style influences the virtual audience's response. For example, if the conductor's tempo is considered to be inappropriate for a particular piece, the audience will start whispering audibly in the background as a cue that they are not appreciating the performance. If the player does not redeem him or herself, the audience will jeer at the end of the performance. Conversely, if the conductor does well, enthusiastic applause will follow the performance (Dillon et al., 2006). The most significant limitation of the controller in this context is that is only possible to track the right hand. Nevertheless, this was not viewed as a critical shortcoming as the right hand is commonly used by conductors for conveying both dynamics and tempo information. The left hand is generally used by conductors in a very personal way which defies any sort of classification (Dillon et al., 2006).

Software facilitating three-dimensional movement
Some software and games designers have taken an alternate approach to facilitating three-dimensional movement in virtual spaces by using motion tracking and other techniques to track human movements. For example, CamSpace is a computer program that turns any object into a 3D controller by using a webcam for motion-tracking (CamTraxTechnologies, 2009). This approach would be cost effective; the software is free to download and any object can be used as a controller. In fact, the actual object to be used in the virtual space could be used in real space. For example, a pair of surgical scissors could act as the controller in a surgery simulation. The software also allows for multiple controllers so that team activities become possible. There are two obvious disadvantages to this approach. First, because any object can be used as a controller, there is no possibility for haptic feedback which is considered essential for many simulations including surgery simulations (Hayward et al., 2004). Second, the degree of interaction possible with the controllers is still at a fairly primitive stage. The software only came out of beta testing within the last six months, so this functionality may improve significantly.

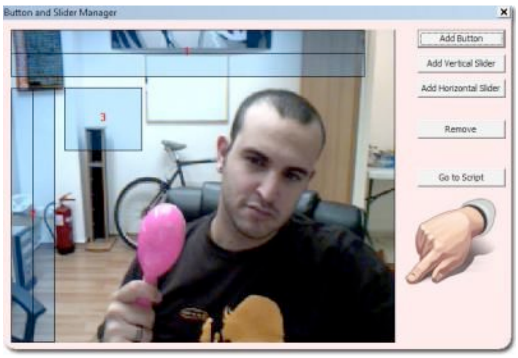

Figure 8: A user customizing a controller using the CamSpace software interface.

Figure 9: A user using his whole body as a controller in Microsoft's Project Natal

Another interesting development in software, consoles and games development, which could have broad implications for educational applications, is Project Natal by Microsoft. Project Natal refers to a venture that allows players to interact with Xbox 360 games by moving their hands and bodies in front of a screen, in a manner reminiscent of how people play games on Nintendo Wii consoles. The significant difference is that players will not need any sort of controller. All that is required is a camera bar and a microphone which sits above or below the screen to record a player's movements. It has been reported that Project Natal will be made available as an upgrade to existing Xbox 360 consoles (Crecente, 2009; Greene, 2009; Stein, 2009). Low cost will be an attractive feature of this system but again, the scope of use in three-dimensional simulations will be limited by the lack of haptic feedback. Additionally, pinpointing the positions of multiple players and correctly identifying distance from the camera are the most significant challenges that developers of this technology face (Stein, 2009). There is also the potential for lag if the image recognition software that analyses the video stream is not fast enough to respond to a player. Finally, Project Natal's main competitor, the Nintendo Wii, offers a variety of controllers that lets players hold on, press buttons and experience force feedback. In contrast, the gesturebased games facilitated by Microsoft's offering provide only visual and audio feedback and consequently, may feel flat by comparison (Greene, 2009). However, there are some obvious uses for the system if it can be used to broaden its range of application.

Similarly, Softkinetic is a Belgium-based company that is striving to let video-game players use a wider range of more-natural movements to control on-screen action. The Softkinetic software is designed to work with depth-sensing cameras, which can be used to determine a player's body position, gestures and movements (Naone, 2008). 'You don't need a controller in your hand,' says CEO Michel Tombroff. 'You don't need to wear a special outfit. You just come in front of the camera in your living room, and you start playing by moving your entire body' (Naone, 2008). The limitations of this technology are similar to those discussed in relation to Project Natal but the developers are confident that it will find wide application including health-care monitoring or applications in the field of ubiquitous computing (Naone, 2008).

Conclusion and implications

This paper has documented the quest for the Holy Grail of tactile precision, natural movement and haptic feedback in 3D virtual spaces. Controllers and software interfaces that enable authentic three-dimensional movement help leverage the considerable educational affordances inherent in these immersive environments. This paper reviewed past research studies as well as selected IT and gaming blog posts on the use of tactile precision in three-dimensional immersive learning environments, yielding a comprehensive review of the available technologies engineered to facilitate the creation of simulations as metaphors for authentic experiences. Controllers included tangible user interfaces (TUIs), haptic devices, floor devices and other gaming controllers. The affordances, advantages, challenges and educational uses of each were considered in detail and where appropriate, directions for future research were flagged. Possible software solutions were also examined along with the challenges and merits implicit in each.

Already, the educational benefits of authentic movement in virtual environments are being exploited in simulations and in other educational contexts including surgery simulations, the training of orchestral conductors and flight simulators. The reasons for this ready adoption are numerous and include low cost and low risk in comparison to real life training scenarios, the facility of learning by doing, convenience and flexibility, and the benefits of immersion and engagement. Though the challenges to developing effective controllers and software are significant, it is anticipated that given time and resources, considerable advances will be made on all fronts but particularly in relation to haptic devices which to date provide the most complete experiences. Even so, it seems inevitable that alternative solutions will be utilized in differing educational contexts, while the quest for the Holy Grail continues.

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